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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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Cardiff Road
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1. Your reference — SHG/P501126

2. Patent application number *(The Patent Office will fill in this part)* — 0224503.3 — 22 OCT 2002

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — University College Cardiff Consultants Limited
   PO Box 497
   56 Park Place
   CARDIFF
   CF10 3XR

   Patents ADP number *(if you know it)* — ADP - 00798603009

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — Semiconductor Optical Devices

5. Name of your agent *(if you have one)* — URQUHART-DYKES & LORD

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — Three Trinity Court
   21-27 Newport Road
   CARDIFF
   CF24 0AA

   Patents ADP number *(if you know it)* — 1644025 ✓

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

   NO

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	9
Claim *(s)*	
Abstract	
Drawing *(s)*	5 + 5

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Date

URQUHART-DYKES & LORD 21.10.02

12. Name and daytime telephone number of person to contact in the United Kingdom — Stewart Gibson 029 2048 7993

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SEMICONDUCTOR OPTICAL DEVICES

The present invention relates to semiconductor optical devices, particularly but not solely for use in the field of bio-chemical or bio-medical analysis.

The use of optical techniques for the analysis of biological samples is a field of increasing importance, particularly in view of its potential for analysis at a molecular level. Various optical systems have been proposed hitherto: these systems have made use of a laser or other light emitter for directing light onto the samples, and a separate photodetector for picking up light from the samples; typically the samples have been marked with a fluorescent dye, such that the incident light stimulates the sample to cause the emission of light of a different wavelength, which is picked up by the photodetector.

We have now devised semiconductor optical devices which provide both light emission and light detection, enabling integration of an analytical system and providing a number of consequent advantages.

In accordance with the present invention, there is provided a semiconductor optical device comprising a single substrate arranged for emitting light for incidence on a sample and also responsive to light received from said sample, the device further comprising means for monitoring a characteristic of the device which varies in dependence upon said light received from said sample.

The device may include a photodetector, integrated on its substrate, for responding to the received light and providing an electrical output signal depending thereon. The photodetector may respond to received light of the same wavelength as the light emitted by the device, for example reflected from a sample, and/or it may respond to received light of a different wavelength, for example light emitted by the sample in response to stimulation by the light emitted by the device: such stimulated light emission may be produced by

fluorescence.

Instead, the device may be such that the received light affects the electrical properties of the device and so alters its current-voltage or impedance characteristic. In this case the monitoring means is arranged to monitor the current-voltage characteristic of the device, which varies depending on the received light (particularly the intensity thereof).

The device may comprise an array of light emitters integrated on the common substrate, these light emitters operating independently of each other and the monitoring means being arranged for monitoring the relevant device characteristic in respect of each emitter, independently of the others. The device may then be used for performing an analytical test on a plurality of samples, one for each light emitter. The device preferably comprises a surface-emitting device, with an array of surface regions emitting light from the corresponding array of emitters, for the samples to be positioned in a similarly corresponding array over that surface. For example, a second substrate may be disposed over the device surface, this second substrate being formed with an array of recesses or chambers or flow ducts for receiving respective samples. The second substrate may be integrated with the device, or it may comprise a separate component.

The device preferably comprises a resonant cavity light emitting device, for example a resonant cavity LED or a laser, preferably a vertical-cavity, surface emitting laser (or VCSEL).

A secondary optical cavity may be disposed over the emitting surface of the device, to form a coupled-cavity system, the secondary cavity including a chamber or flow duct for a sample.

In the case of a resonant cavity device, preferably a reflector thereof, through which the light output is emitted, comprises a plurality of alternating layers of high and low refractive index material, in which a layer of absorbing

material is incorporated. This absorbing layer serves to absorb light of a wavelength different from (typically longer than) the light emitted by the laser: in absorbing light, electron-hole pairs are generated in the absorbing layer, so altering the current-voltage characteristic of the device. Because of its position at a node of the optical standing wave within the resonant cavity, the absorbing layer does not affect the light emitted by the device. Typically the absorbing layer may be disposed within one of the layers of the reflector, particularly within one of the high refractive index layers.

The device may typically comprise a two-terminal, vertically integrated device, with the monitoring means arranged to monitor the current-voltage characteristic of the device. For example, a constant voltage source may be connected across the device and the monitoring means arranged to monitor the current flow: instead, the device may be fed from a constant current source and the monitoring means arranged to monitor the voltage across the device.

The monitoring means may comprise a circuit, part of which is integrated on the semiconductor substrate of the device.

Also in accordance with the present invention, there is provided a semiconductor optical device comprising a substrate in which a resonant cavity emitter is formed, a multi-layer reflector of the resonant cavity emitter incorporating an absorbing layer for light of a wavelength different from the light emitted by the device.

It will be appreciated that the devices in accordance with the present invention may be miniaturised and mass produced, to provide mass-produced devices which are inexpensive yet reliable. Moreover, the samples may be positioned very closely to both the light emitter region and the light receiving region of the device, providing for high detection efficiency. It is particularly advantageous to provide for independent testing of an array of samples on the

same device.

Embodiments of the present invention will now be described by way of examples only and with reference to the accompanying drawings, in which:

FIGURE 1 is a schematic view of a prior art system for the optical analysis of biological samples;

FIGURE 2 is a diagrammatic section through a semiconductor laser device forming a first embodiment of the present invention;

FIGURE 3 is a section, on enlarged scale, of part of the device of Figure 1, showing the optical intensity variation therein;

FIGURE 4 is a diagrammatic section through a semiconductor laser device forming a second embodiment of the present invention;

FIGURE 5 is a view of the device of Figure 4; and

FIGURE 6 is a diagrammatic section through a semiconductor laser device forming a third embodiment of the present invention.

Referring to Figure 1, there is shown a prior art system for the optical analysis of an array of biological samples, each of the samples being marked with a fluorescent dye. The system comprises a tray T the upper surface of which is formed with a two-dimensional array of recesses or wells R which receive respective samples. A laser or other source S is provided to direct light onto the samples: means are provided for scanning the light beam onto the samples in succession. A photodetector P is provided to pick up the light emitted, by fluorescence, from the successive samples, the output of the photodetector being passed to a processing unit.

Referring to Figure 2, there is shown a semiconductor device in accordance with the present invention in the form of a vertical-cavity, surface-emitting laser (or VCSEL), for use in performing an analytical test on a biological sample. The device comprises a semiconductor substrate having cavity layers

10,12 and an intermediate gain material layer 14, and upper and lower multi-layer reflectors 16,18: each reflector comprises a plurality of alternating layers of high and low refractive index materials, each layer being a ¼ wavelength thick. The device is provided with electrodes 20,22 on its top and bottom surfaces: in use, a voltage is applied between the upper and lower electrodes 20,22 to provide a current flow through the device; this current excites the device to cause lasing within its resonant cavity, the laser output light O being emitted through the top surface of the device.

In accordance with the present invention, the laser output is directed onto a biological or bio-chemical sample (not shown) positioned on or above the device, the sample being marked with a fluorescent dye. The laser output O stimulates the sample, causing the emission of light of a longer wavelength than the laser output light: some of the light D emitted from the sample returns and passes into the device.

The upper reflector 16 includes a layer 24 of narrow bandgap material, forming an absorbing layer for the light of the wavelength emitted by the sample. The absorbing layer 24 is disposed at a position which corresponds with a node in the internal optical standing wave of the device cavity: the variations in optical intensity are shown by the trace W in Figure 3; accordingly, the absorbing layer 24 does not absorb the light emitted by the device or affect its lasing characteristics. Two or more absorbing layers 24 may be included in the reflector 16, within respective layers or between respective pairs of layers thereof. In order to accommodate the absorbing layer (typically 10 to 50nm thick), the spacing between the respective pair of layers of the reflector may be altered from the ¼ wavelength value. In the example shown, the absorbing layer is disposed within one of the high refractive index layers of the reflector.

In use, the light D picked up by the device, from the sample, is absorbed by the absorbing layer 24, generating hole-

electron pairs, which accordingly alter the current-voltage characteristic of the device. A constant voltage source may be connected across the device, and means provided to monitor the current flow, the current varying in dependence on the intensity of light D received from the sample. Alternatively, the device may be fed from a constant current source, and means provided to monitor the voltage across the device, which again varies in dependence upon the intensity of light D received from the sample.

In a modification of the device of Figure 2, the device may comprise a resonant cavity LED instead of a VCSEL.

Referring to Figures 4 and 5, there is shown a semiconductor device in the form of a two-dimensional array of vertical-cavity, surface-emitting lasers L, for use in performing an analytical test on a corresponding array of biological or bio-chemical samples B. The device comprises a semiconductor substrate having cavity layers 10,12 and an intermediate gain material layer 14, and upper and lower multi-layer reflectors 16,18: each reflector comprises a plurality of alternating layers of high and low refractive index materials, each layer being a ¼ wavelength thick. The device is provided with an array of electrodes 20 on its upper surface and with a common or ground electrode 22 on its bottom surface. In use, a voltage is applied between each upper electrode 20 and the bottom electrode 22, to provide respective current paths through the device. In each current path, the device is excited to cause local lasing action within the device cavity, the laser output light O being emitted through the spaces or windows 20a between the electrodes 20 on the top surface of the device. It will be appreciated that the arrangement forms a two-dimensional array of lasers.

An interface layer 26 is formed over the upper electrode 20 and upper reflector 16, and a sample-receiving substrate 28 is disposed over the interface layer 26. The upper surface of the sample-receiving substrate 28 is formed

with a two-dimensional array of recesses or wells 29, for receiving respective samples B: the wells 29 are aligned with respective windows 20a between the upper electrodes 20 of the device; thus, there is one independent laser for each sample well 29. The sample-receiving substrate 28 may be integrated with the semiconductor device: alternatively, it may comprise a separate component, as shown in Figure 5, which can be removed and disposed off if desired.

The upper reflector 16 of the device of Figure 4 includes a layer 24 of narrow bandgap material, forming an absorbing layer for light returned by each sample. The absorbing layer 24 is positioned, within the reflector 16, in the same manner as described for figure 2.

Light O emitted from each laser is incident on the corresponding sample B, which is marked with a fluorescent dye, thus stimulating the sample to cause emission of light of longer wavelength. Some of this light returns to the respective laser L of the device and is absorbed locally by the absorbing layer 24, with the result of altering the current-voltage characteristic of the respective laser L. A constant voltage source may be connected across each laser L, via its respective upper electrode 20 and the ground electrode 22, and means provided for monitoring the current flow through that laser: alternatively each laser L may be fed from a constant current source, and means provided for monitoring the voltage across that laser.

In a modified form of the embodiment shown in Figure 4, each laser L may be provided with a photodetector, integrated within the semiconductor device, to receive light D returned from the respective sample B, the absorbing layer 24 being dispensed with. The photodetector of each laser will detect laser light reflected back from the respective sample, or light emitted from the sample in response to stimulation by the laser light. The outputs of the photodetectors are connected to a monitoring circuit.

It will be appreciated that the device of Figure 2, or the above-described modified form thereof, may comprise an array of resonant cavity LEDs, instead of a VCSELs

In another modified form of the embodiment shown in Figure 4, again with the absorbing layer 24 dispensed with, the output light from each laser is reflected by the respective sample and returns into the laser, acting to modify the current-voltage characteristic of the laser. A circuit is connected to the electrodes 20 of the lasers, to monitor the current through and/or voltage across each laser.

Referring to Figure 6, there is shown a semiconductor device in the form of a vertical cavity, surface-emitting laser, having a second optical cavity 30 in contact with it, the cavity containing a biological or biochemical sample or including a flow duct for such a sample. The device comprises a semiconductor substrate having cavity layers 10,12 and an intermediate gain material layer 14, and upper and lower multi-layer reflectors 16,18: each reflector comprises a plurality of alternating layers of high and low refractive index material, each layer being a ¼ wavelength thick. The device is provided with electrodes 20,22 on its top and bottom surfaces: in use, a voltage is applied between these electrodes to provide a current flow through the device, exciting the device to cause lasing within the device cavity and emission of laser output light O through the top surface of the device.

The second optical cavity 30 comprises a container 32 for the sample B, the upper side of the container 32 comprising a multi-layer reflector 34 of construction corresponding to the reflectors 16,18 of the laser device. A transparent spacer 36 is interposed between the underside of the container 32 and the upper surface of the device.

The two optical cavities form a coupled-cavity system, the emitted laser light O being transmitted through the sample B, then reflected, by the reflector 34 of the second cavity, back into the laser device. This return or feedback light D

is amplified within the laser device and so modifies its current-voltage characteristic. A circuit is connected to the electrode 20 of the laser, to monitor the current through and/or voltage across the laser.

In a modified form of the embodiment of Figure 6, the reflector 16 of the device includes a narrow bandgap absorbing layer, in the same manner as the corresponding reflectors of the devices shown in Figures 2 and 4, for absorbing stimulated-emission light from the sample B, of a different wavelength to the laser output. In this form, the device may comprise a resonant cavity LED, instead of a VCSEL.

It will be appreciated that, in each of the above-described embodiments, the monitoring means may comprise a circuit part of which is integrated on the semiconductor substrate of the device.

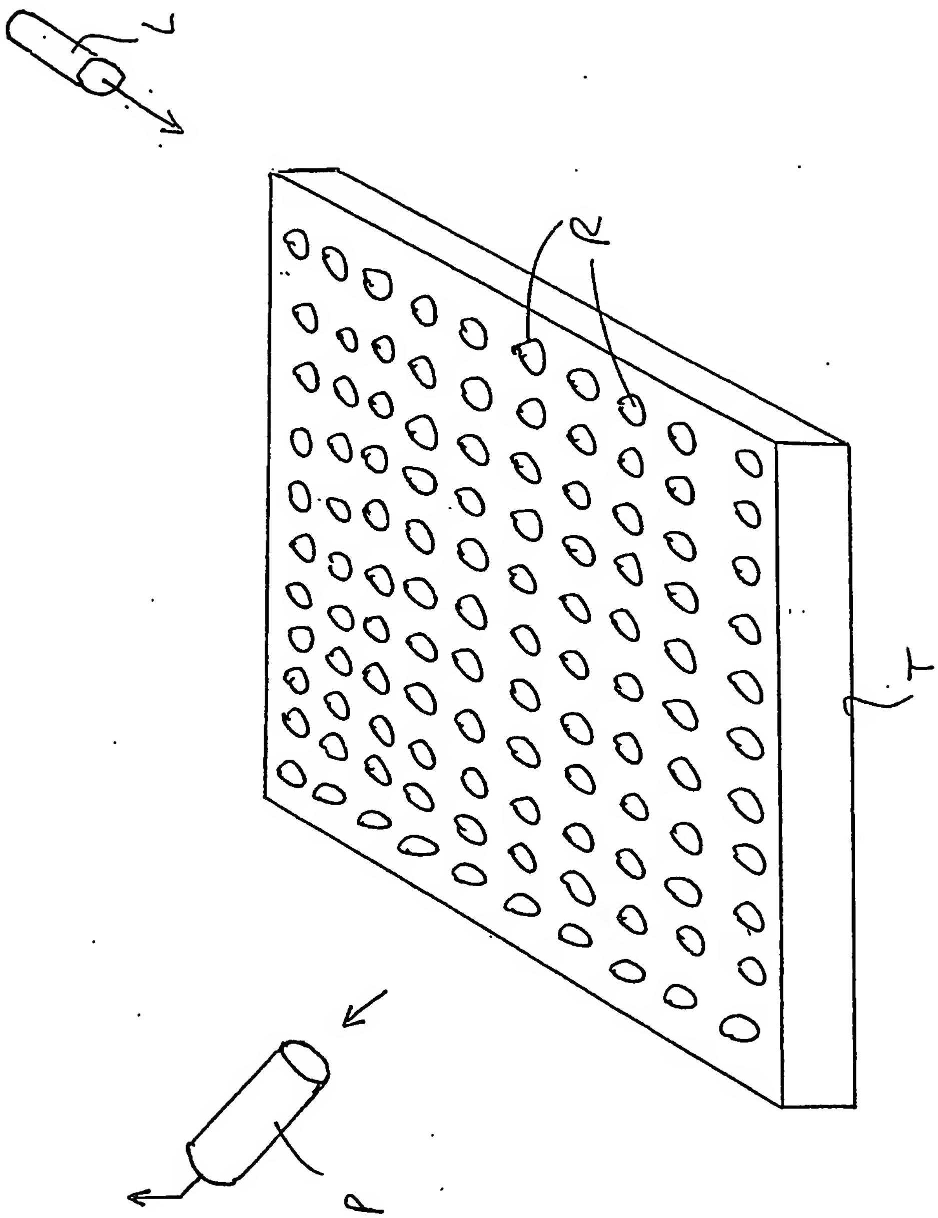

Figure 1

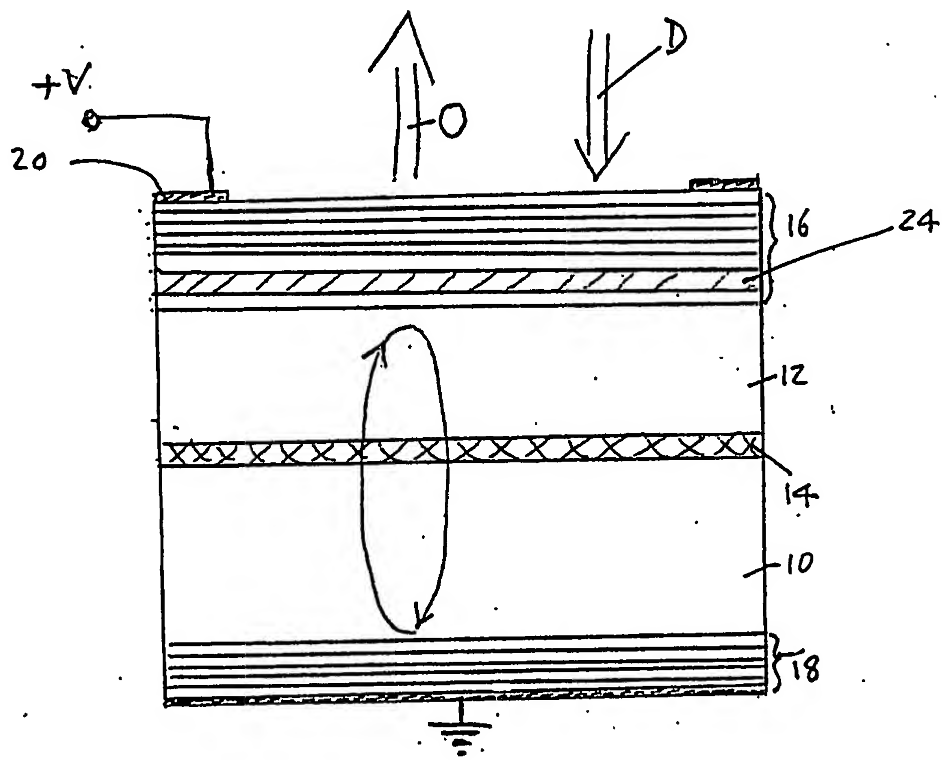

Figure 2

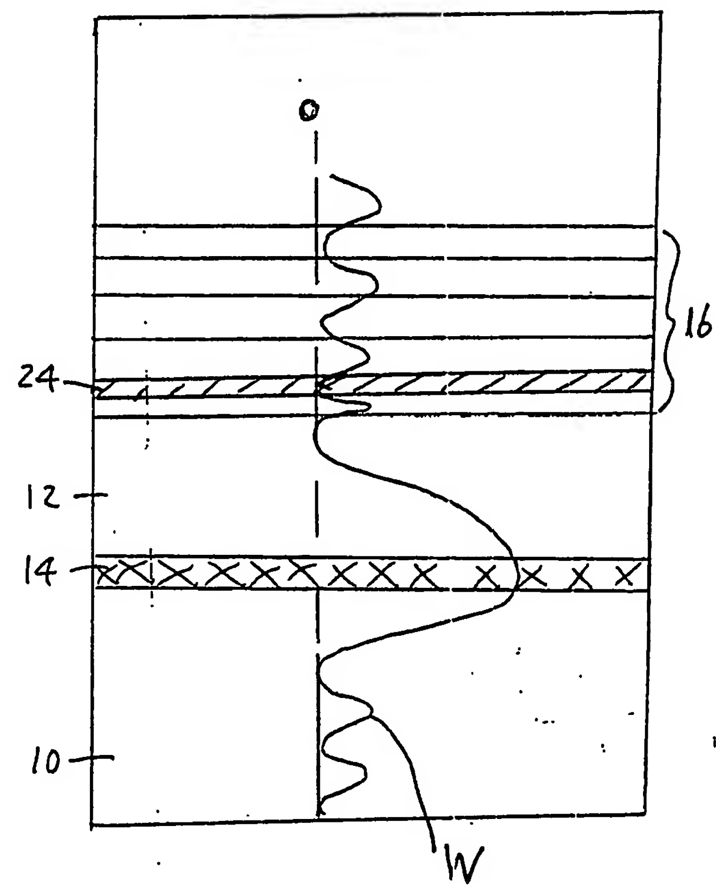

Figure 3

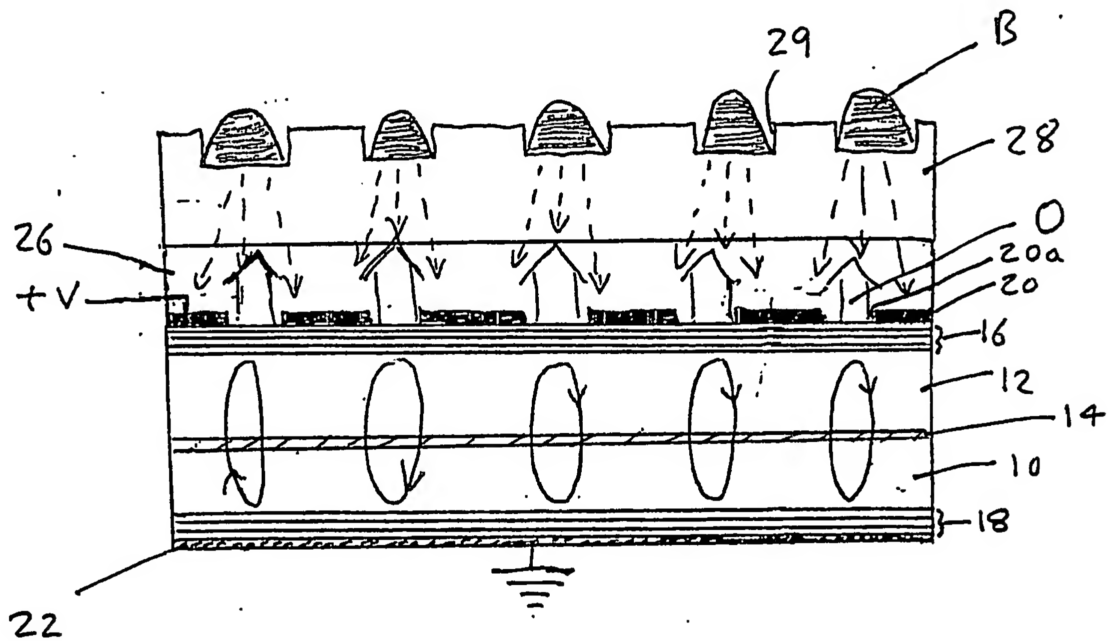

Figure 4

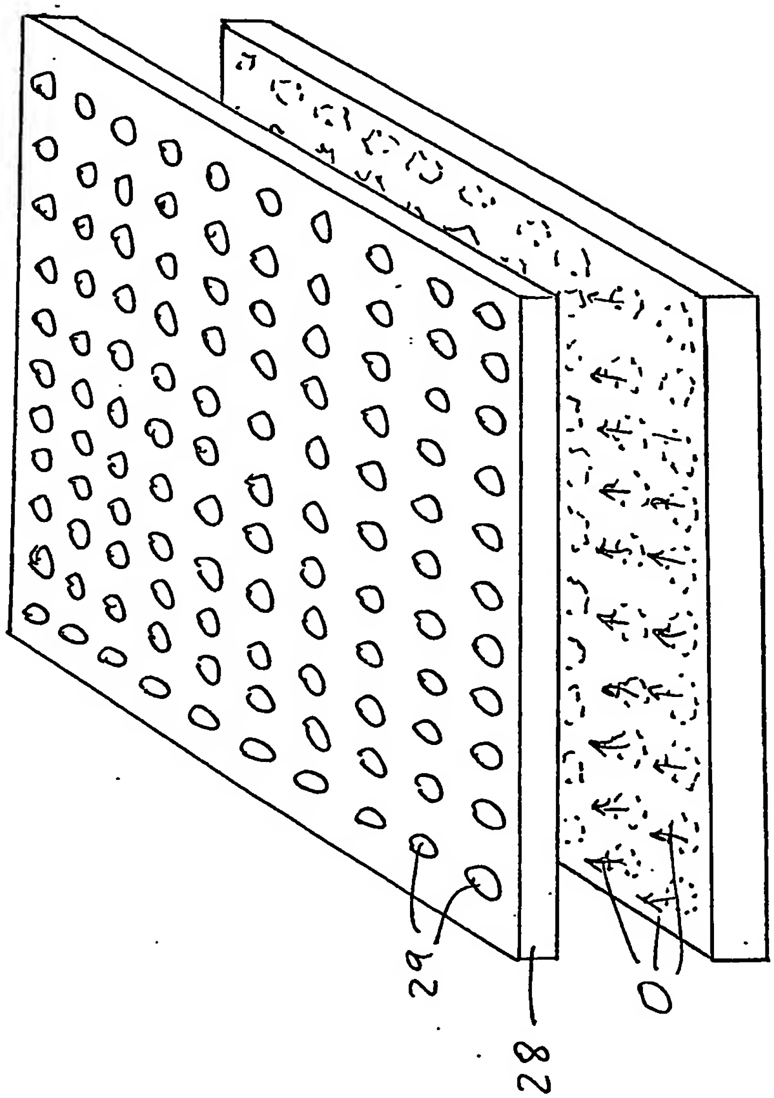

Figure 5

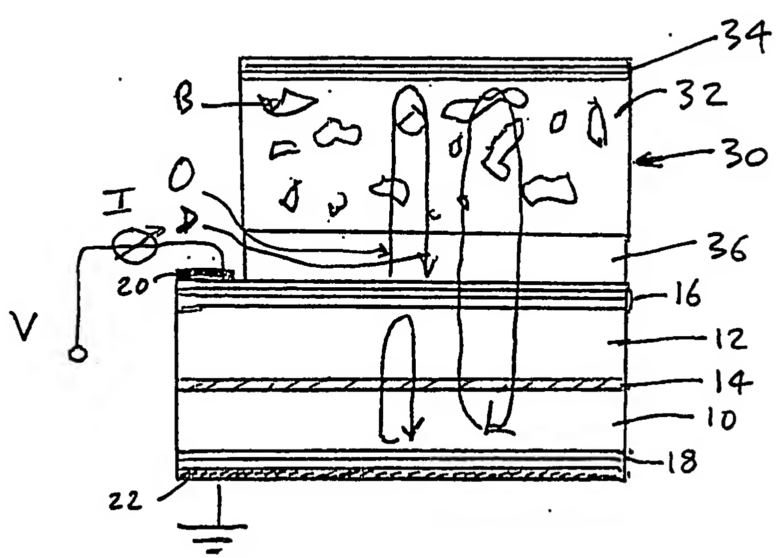

Figure 6